1:19-CV-1170

Exhibit 3

US008390206B2

(12) **United States Patent**
Ruxton

(10) **Patent No.: US 8,390,206 B2**
(45) **Date of Patent: Mar. 5, 2013**

(54) **VARIABLE-EFFECT LIGHTING SYSTEM**

(75) Inventor: **James Ruxton**, Hamilton (CA)

(73) Assignee: **Pharos Innovations, Inc.**, Toronto (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/525,939**

(22) Filed: **Jun. 18, 2012**

(65) **Prior Publication Data**

US 2012/0319600 A1 Dec. 20, 2012

Related U.S. Application Data

(63) Continuation of application No. 12/063,905, filed on Jul. 3, 2008, now Pat. No. 8,203,275.

(30) **Foreign Application Priority Data**

Aug. 16, 2005 (CN) 2005 1 0092007

(51) **Int. Cl.**
H05B 37/00 (2006.01)

(52) **U.S. Cl.** .... **315/185 R**; 315/224; 315/307

(58) **Field of Classification Search** .... 315/224, 315/209 R, 291, 185 R, 193, 307, 308, 186, 315/192
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,573,210 B2 *	8/2009	Ashdown et al.	....	315/307
8,004,203 B2 *	8/2011	Maxik	....	315/247
2005/0040773 A1 *	2/2005	Lebens et al.	....	315/291

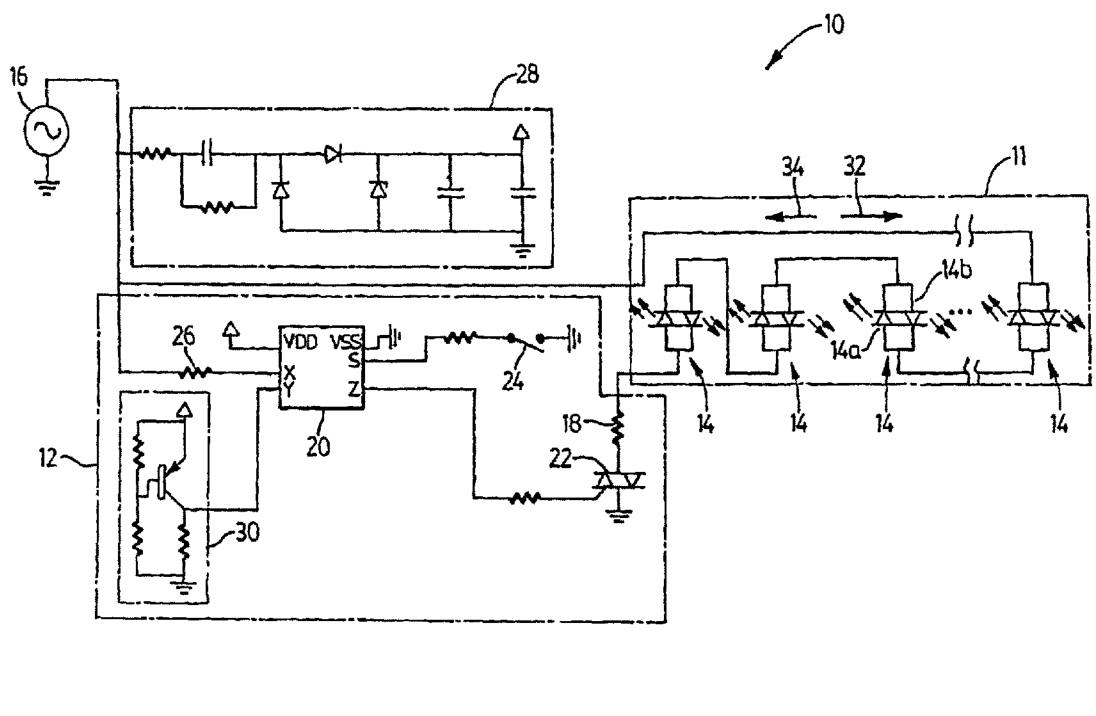
* cited by examiner

Primary Examiner — David H Vu
(74) *Attorney, Agent, or Firm* — Heenan Blaikie LLP

(57) **ABSTRACT**

A variable-effect lighting system includes a lamp assembly and a lamp controller coupled to the lamp assembly. The lamp assembly comprises a number of multi-colored lamps in series with an AC voltage source and in series with each other. Each multi-colored lamp comprises a first illuminating element for producing a first color of light, and a second illuminating element for producing a second color of light. The lamp controller is configured to control the current draw of each said illuminating element, and to adjust the current draw in accordance with the frequency of the voltage source.

12 Claims, 10 Drawing Sheets



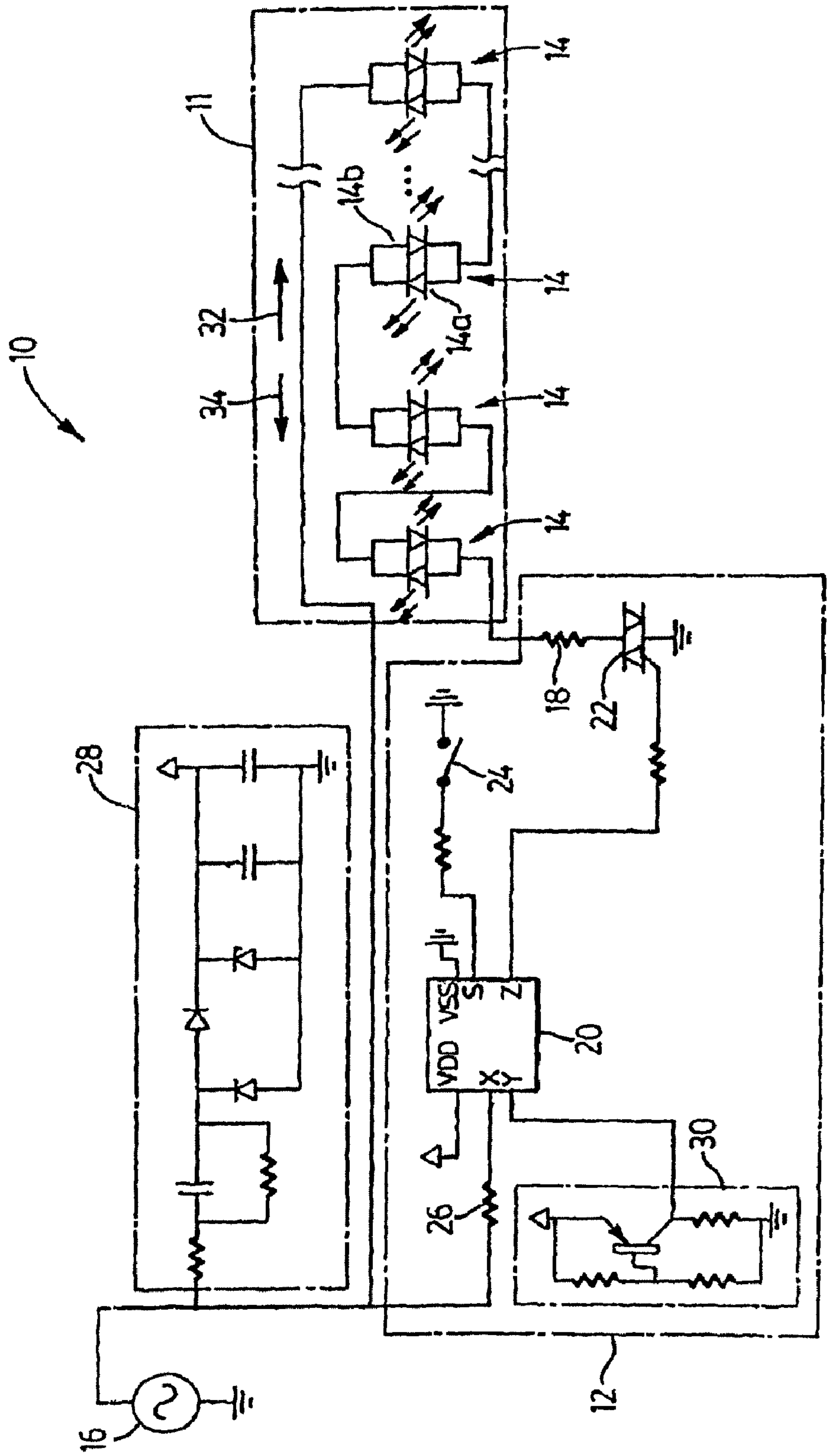

10
11
14
14b
14a
14
14
14
32
34
28
18
22
24
20
VDD
VSS
S
Z
X
Y
26
30
12
16

FIG. 1a

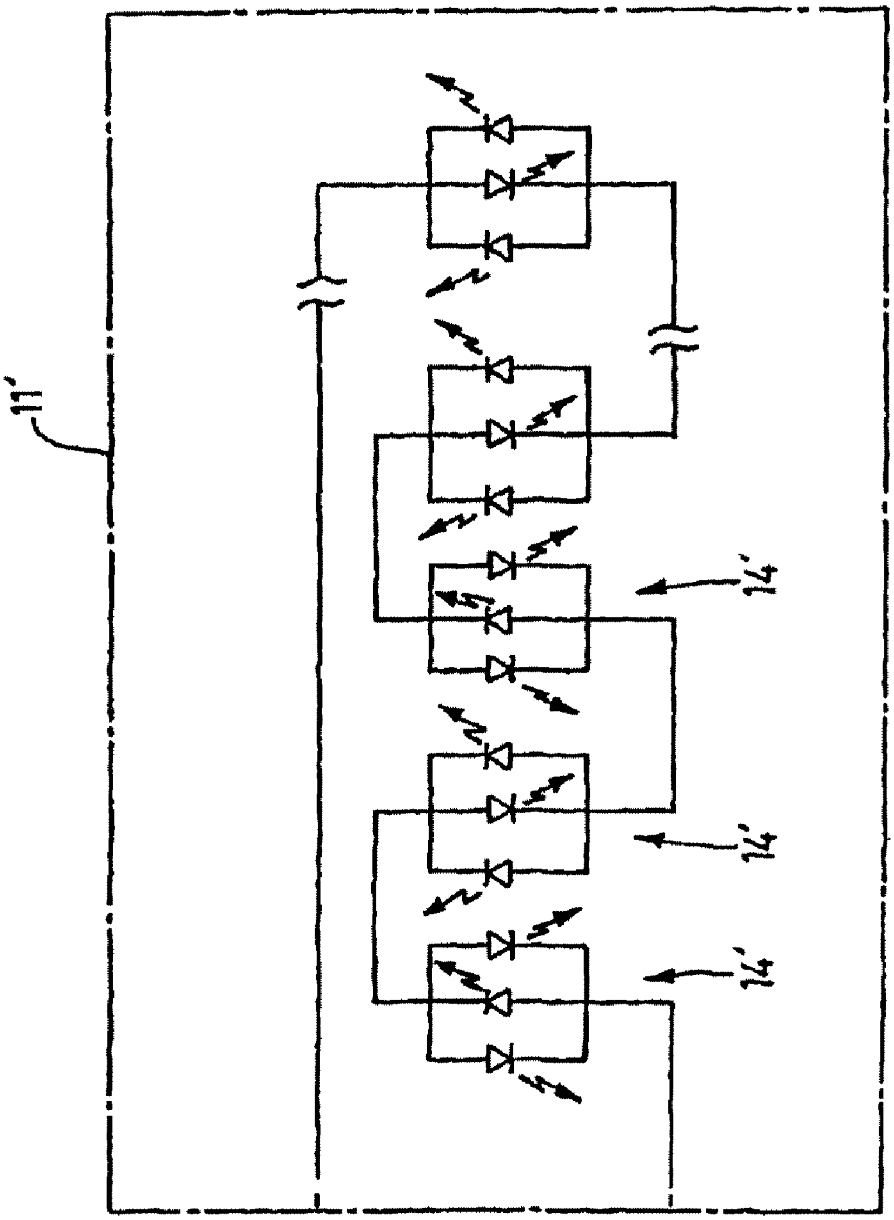


FIG. 1b

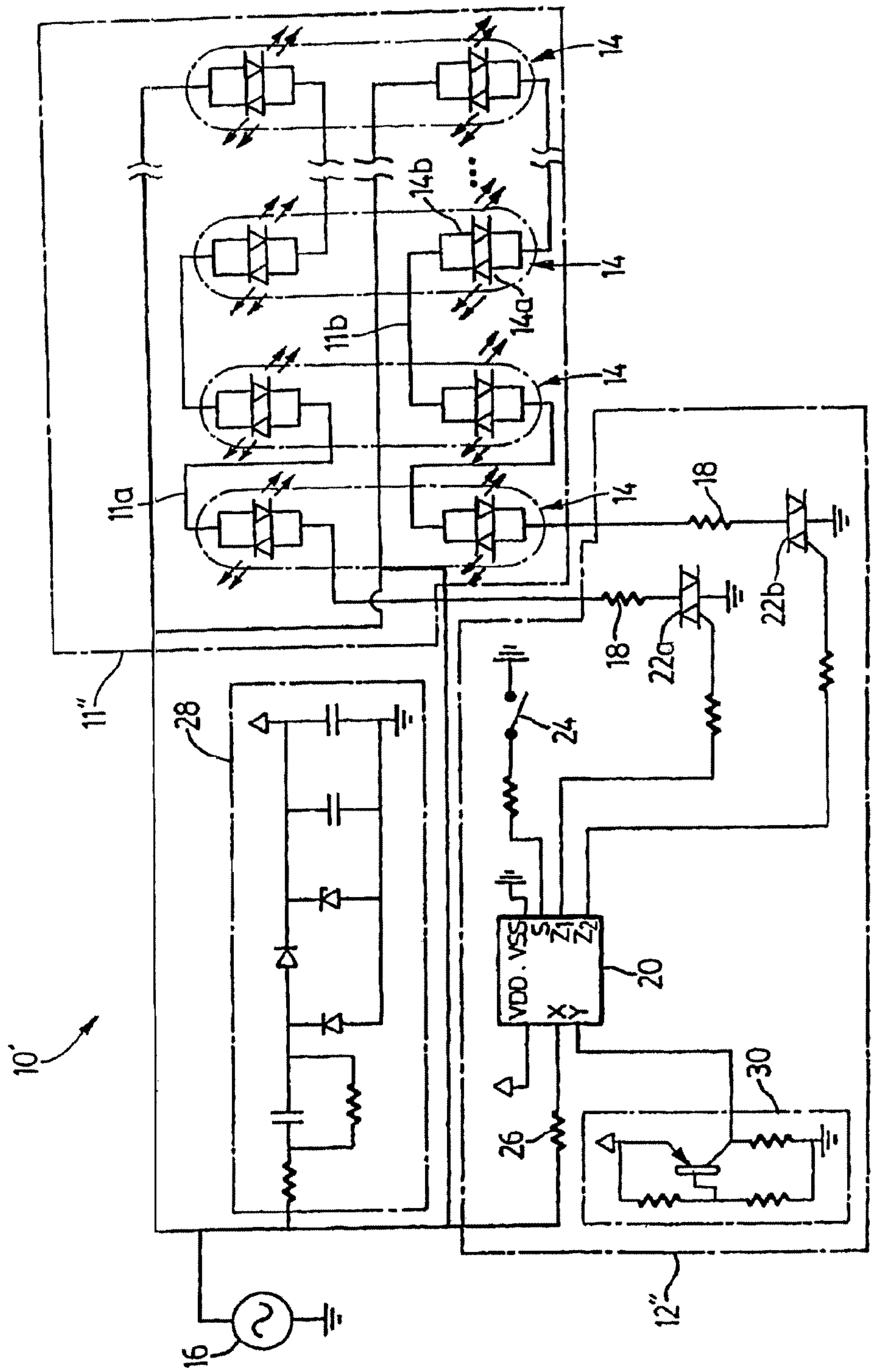

14
14b
14
11b
14a
14
11a
14
18
18
22a
22b
11"
28
24
VDD. VSS
S
Z1
Z2
X
Y
20
10'
26
30
16
12"

FIG. 1c

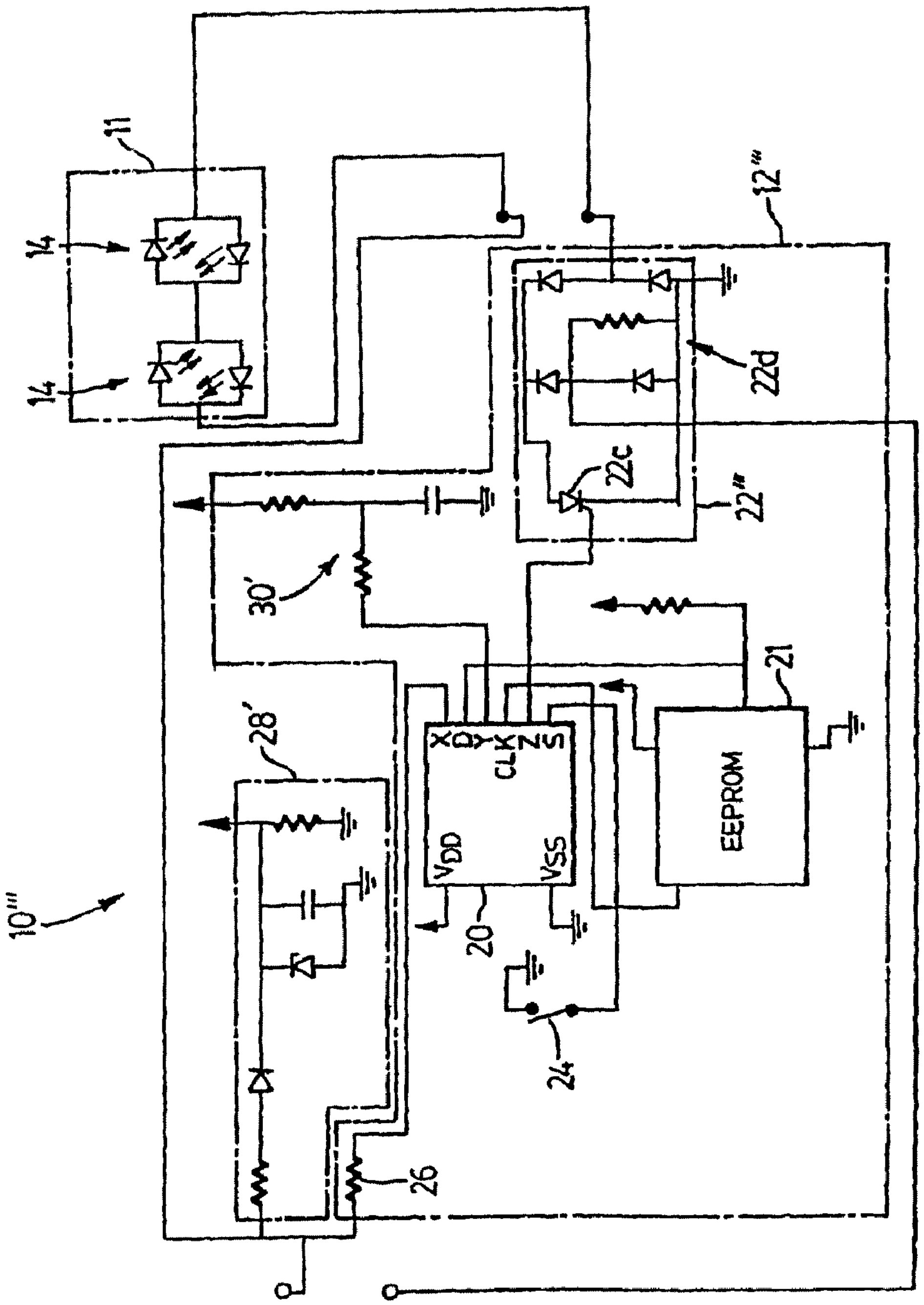
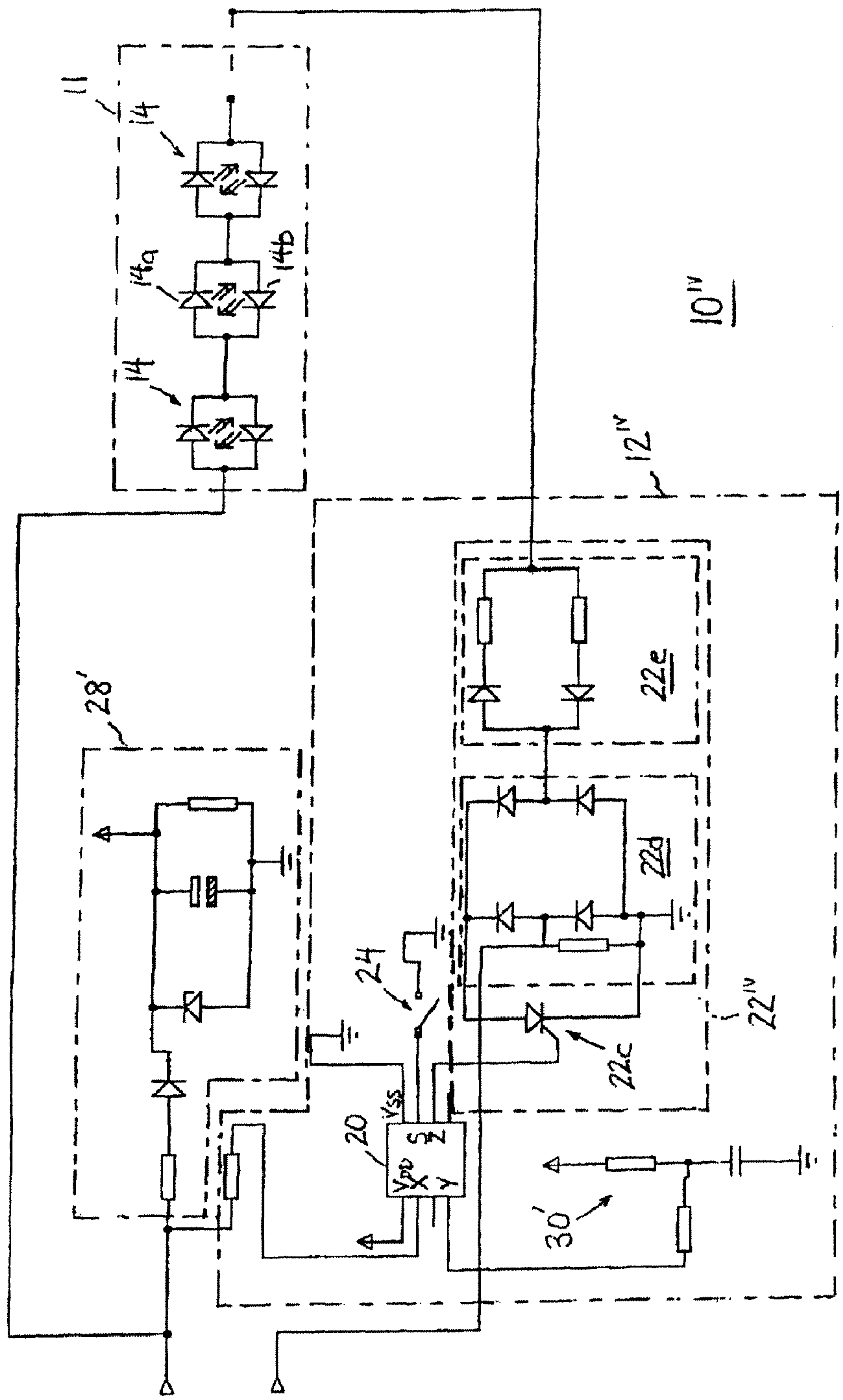


FIG. 1d



11
14
14a
14b
14
10^{IV}
12^{IV}
28'
22e
22d
22^{IV}
22c
24
20
V_{DD}
V_{SS}
S
Z
X
Y
30'

FIG. 1e

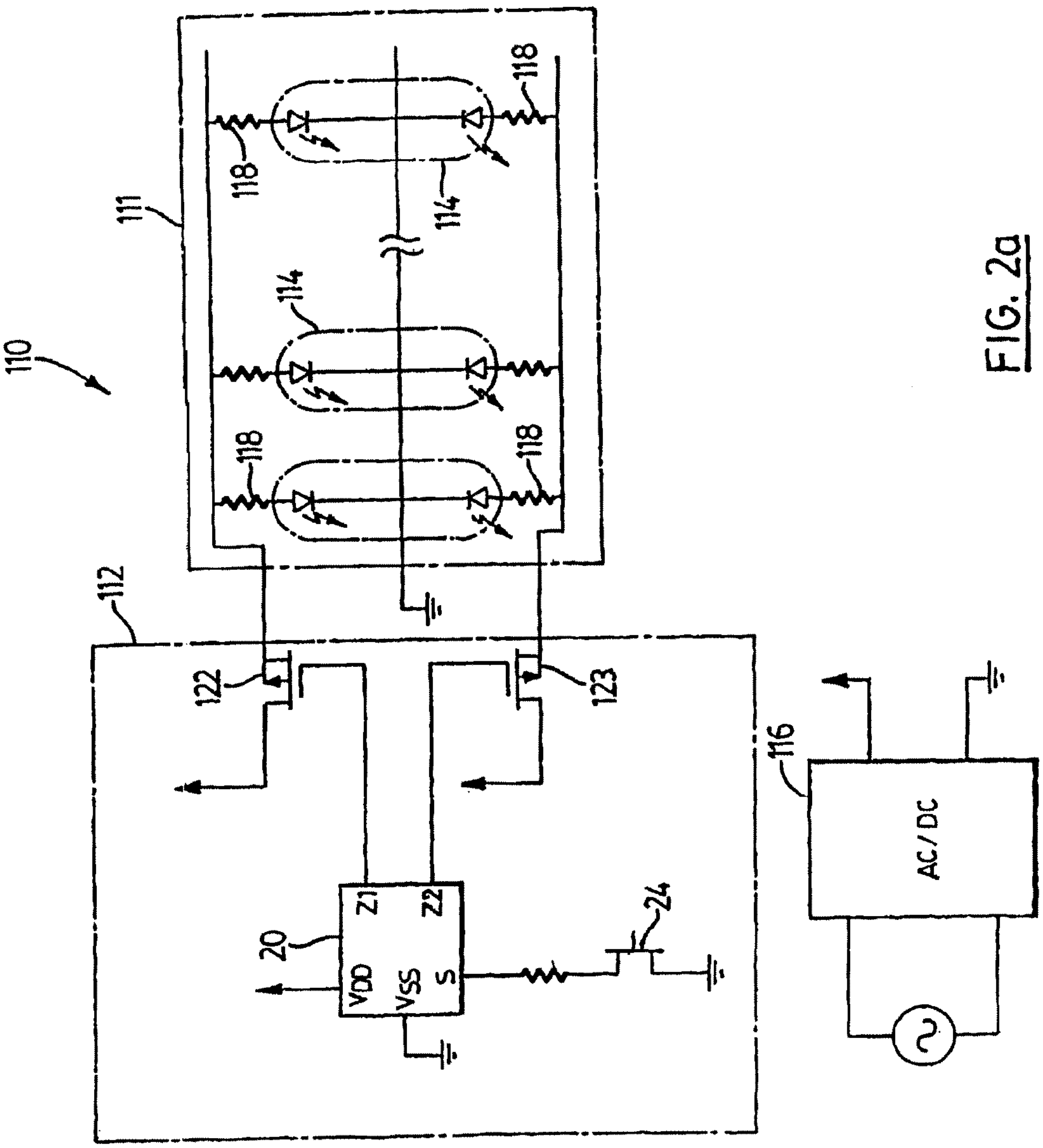


FIG. 2a

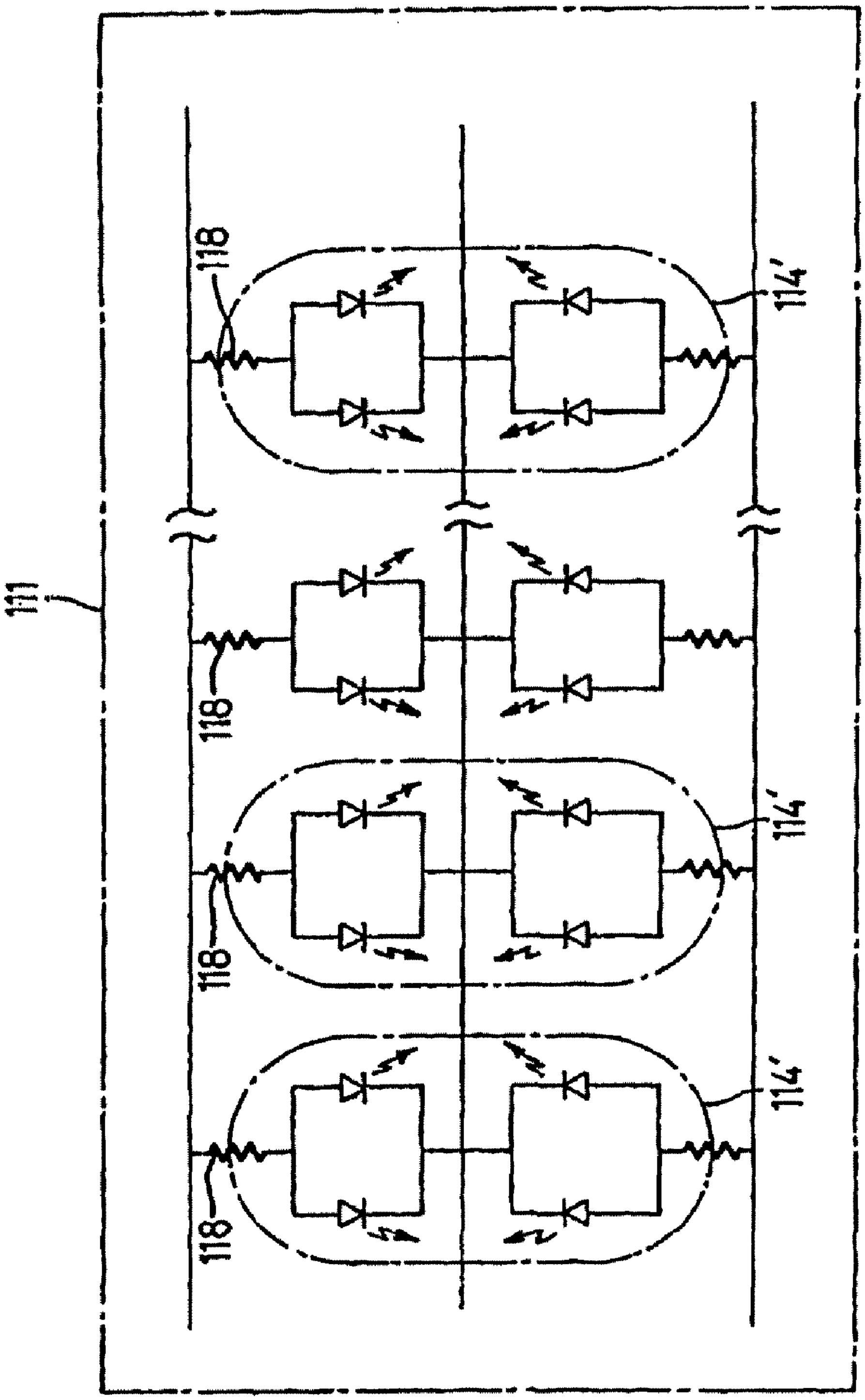


FIG. 2b

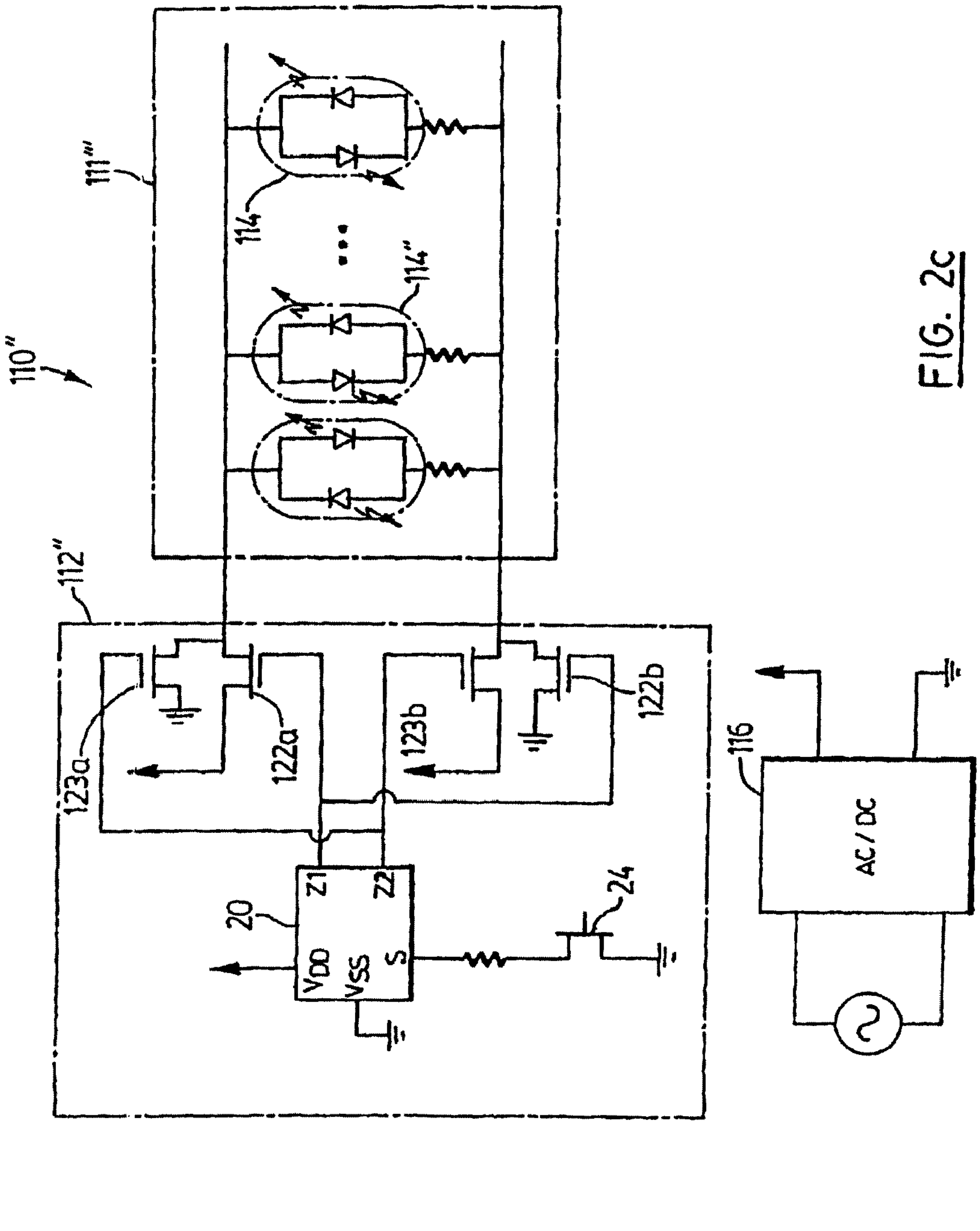

110"
111'''
114
114"
112"
123a
122a
123b
122b
20
Z1
Z2
V_{DD}
V_{SS}
S
24
116
AC / DC

FIG. 2c

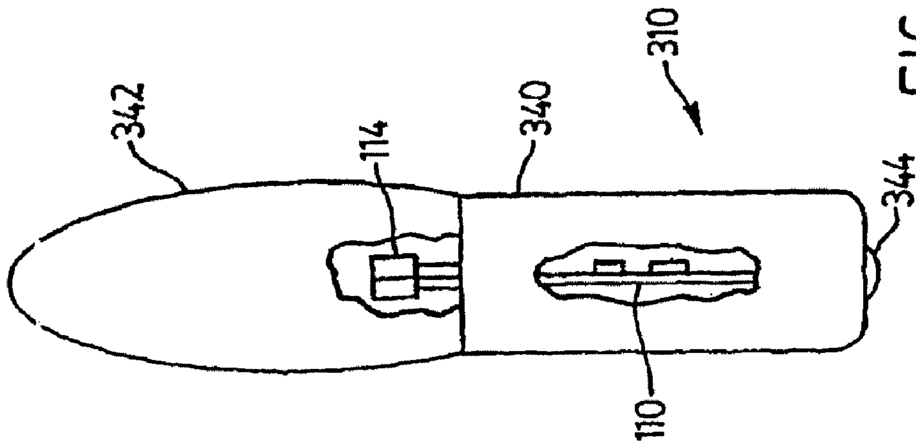

342
114
340
310
344
110

FIG. 4

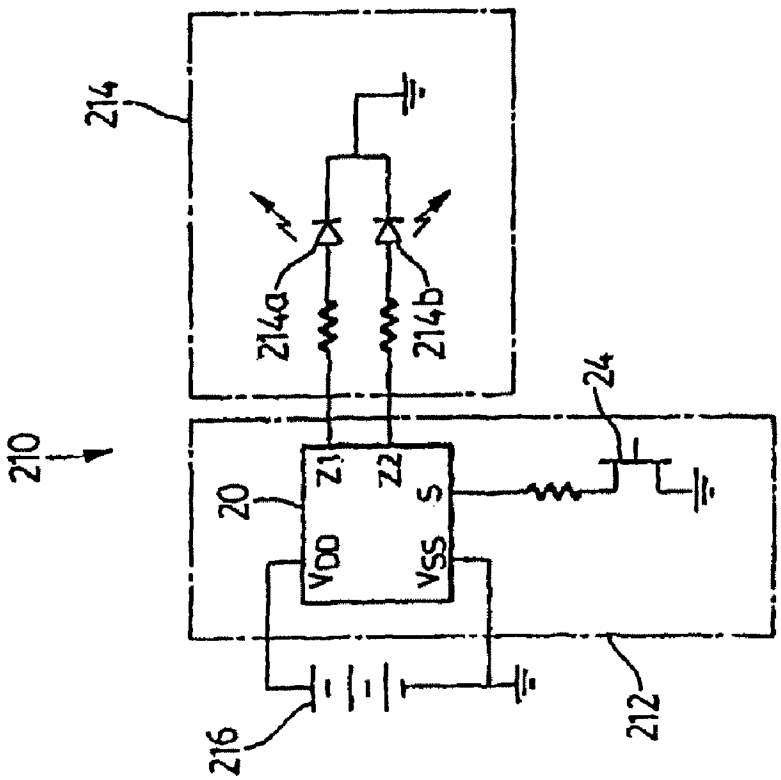

214
214a
214b
210
20
Z1
Z2
S
VDD
VSS
24
216
212

FIG. 3

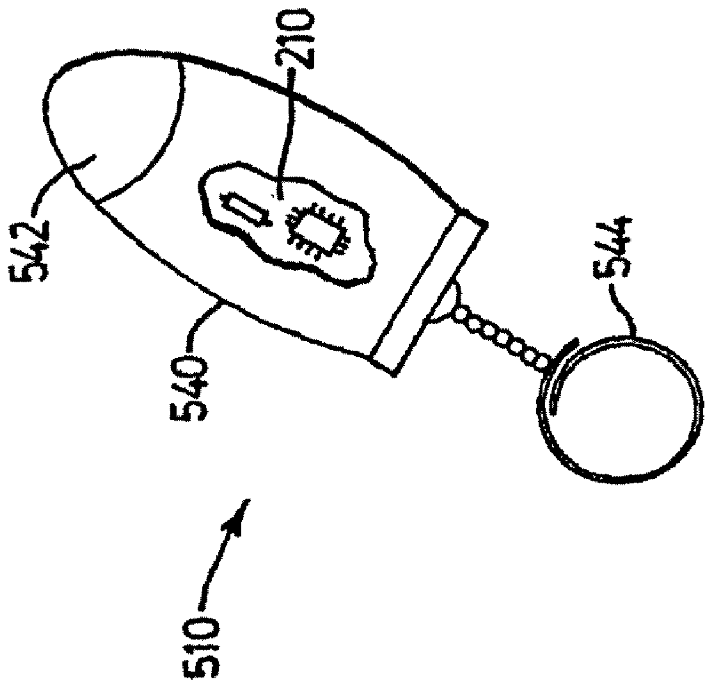


FIG. 5b

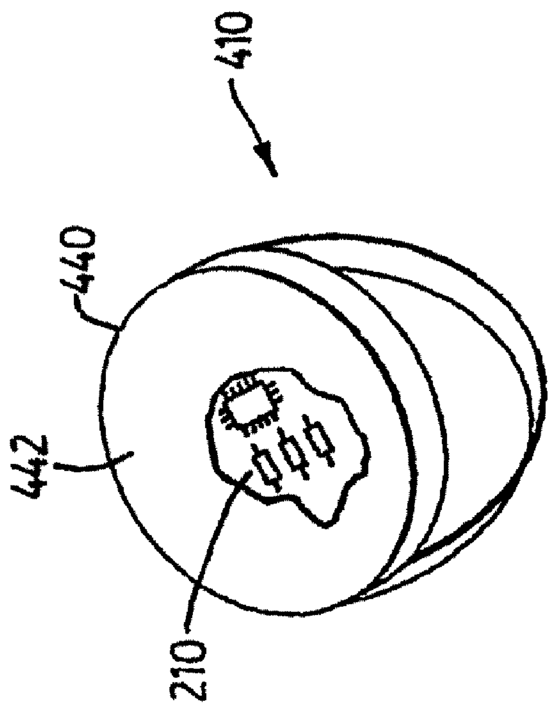


FIG. 5a

VARIABLE-EFFECT LIGHTING SYSTEM

RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application Ser. No. 12/063,905 (now U.S. Pat. No. 8,203,275), entitled "Variable-Effect Lighting System", filed Aug. 16, 2006.

FIELD

This patent application relates to variable-effect lighting systems. In particular, the patent application relates relates to a lighting system having coloured lamps for producing a myriad of colour displays.

BACKGROUND

Variable-effect lighting systems are commonly used for advertising, decoration, and ornamental or festive displays. Such lighting systems frequently include a set of coloured lamps packaged in a common fixture, and a control system which controls the output intensity of each lamp in order to control the colour of light emanating from the fixture.

For instance, Kazar (U.S. Pat. No. 5,008,595) teaches a light display comprising strings of bicoloured LED packages connected in parallel across a common DC voltage source. Each bicoloured LED package comprises a pair of red and green LEDs, connected back-to-back, with the bicoloured LED packages in each string being connected in parallel to the voltage source through an H-bridge circuit. A control circuit, connected to the H-bridge circuits, allows the red and green LEDS to conduct each alternate half cycle, with the conduction angle each half cycle being determined according to a modulating input source coupled to the control circuit. However, the rate of change of coloured light produced is restricted by the modulating input source. Therefore, the range of colour displays which can be produced by the light display is limited.

Phares (U.S. Pat. No. 5,420,482) teaches a controlled lighting system which allows a greater range of colour displays to be realized. The lighting system comprises a control system which transmits illumination data to a number of lighting modules. Each lighting module includes at least two lamps and a control unit connected to the lamps and responsive to the illumination data to individually vary the amount of light emitted from each lamp. However, the illumination data only controls the brightness of each lamp at any given instant. Therefore, the lighting system is not particularly well suited to easily producing intricate colour displays.

Murad (U.S. Pat. No. 4,317,071) teaches a computerized illumination system for producing a continuous variation in output colour. The illumination system comprises a number of different coloured lamps, a low frequency clock, and a control circuit connected to the low frequency clock and to each coloured lamp for varying the intensity of light produced by each lamp. However, the rate of change of lamp intensity is dictated by the frequency of the low frequency clock, and the range of colour displays is limited.

Gomoluch (GB 2,244,358) discloses a lighting control system which includes a lighting control unit, and a string of light units connected to the lighting control unit. The lighting control unit includes a DC power supply unit, a microprocessor, a read-only memory containing display bit sequences, and switches for allowing users to select a display bit sequence. Each light unit includes a bi-coloured LED, and data storage elements each connected in parallel to the DC power output of

the lighting control unit and in series with data and clock outputs of the microprocessor. The microprocessor clocks the selected bit patterns in serial fashion to the storage elements. The data storage elements received each data bit, and illuminate or extinguish the associated LED.

However, Gomoluch requires that complex light units be used. Therefore, there remains a need for a relatively simple variable-effect lighting system which allows for greater variation in the range of colour displays which can be realized.

SUMMARY

This patent application describes a variable-effect lighting system comprising a lamp assembly, and a lamp controller coupled to the lamp assembly.

In a first aspect of this patent application, the lamp assembly comprises a plurality of multi-coloured lamps in series with an AC voltage source and in series with each other. Each multi-coloured lamp comprises a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light. The lamp controller is configured to vary the colour produced by the lamps by varying a conduction interval of each said illuminating element according to a predetermined pattern. The controller is also configured to terminate the variation upon activation of a user-operable input to the controller.

In a second aspect of this patent application, the lamp assembly comprises a plurality of multi-coloured lamps in series with an AC voltage source and in series with each other. Each multi-coloured lamp comprises a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light. The lamp controller is configured to vary the colour produced by the lamps by varying the conduction interval of each illuminating element according to an external signal input to the lamp controller.

In a third aspect of this patent application, the lamp assembly comprises a plurality of multi-coloured lamps in series with an AC voltage source and in series with each other. Each multi-coloured lamp comprises a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light. The lamp controller is configured to control the current draw of each said illuminating element in accordance with the frequency of the voltage source.

In a fourth aspect of this patent application, the variable-effect lighting system includes a first lamp assembly comprising a plurality of first multi-coloured lamps in parallel with an AC voltage source and in series with each other, and a first lamp controller coupled to the first lamp assembly for controlling a first colour of light produced by the first multi-coloured lamps. The lighting system also includes a second lamp assembly comprising a plurality of second multi-coloured lamps in parallel with the AC voltage source and in series with each other; and a second lamp controller coupled to the second lamp assembly for controlling a second colour of light produced by the second multi-coloured lamps. The first lamp controller is configured to vary the first produced colour. The second lamp controller is configured to vary the second produced colour in synchronization with the first produced colour.

In a fifth aspect of this patent application, the lamp assembly comprises a plurality of multi-coloured lamps in parallel with a DC voltage source. Each multi-coloured lamp comprises a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light different from the first colour. The lamp

controller includes a first electronic switch coupled to all of the first illuminating elements and a second electronic switch coupled to all of the second illuminating elements. The lamp controller is configured to set the conduction angle of each illuminating element according to at least one predetermined pattern, the controller being configured with the predetermined patterns.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects will now be described in detail, by way of example only, with reference to the drawings, in which:

FIG. **1***a* is a schematic circuit diagram of a first embodiment of the variable-effect lighting system, showing a lamp controller, and a lamp assembly comprising a string of series-coupled bicoloured lamps;

FIG. **1***b* is a schematic circuit diagram of one variation of the lamp assembly shown in FIG. **1***a;*

FIG. **1***c* is a schematic circuit diagram of a variable-effect lighting system, according to a second embodiment of the variable-effect lighting system;

FIG. **1***d* is a schematic circuit diagram of a third embodiment of the variable-effect lighting system;

FIG. **1***e* is a schematic circuit diagram of a fourth embodiment of the variable-effect lighting system;

FIG. **2***a* is a schematic circuit diagram of an eighth embodiment of the variable-effect lighting system, wherein the lamp assembly comprises a string of parallel-coupled bicoloured lamps;

FIG. **2***b* is a schematic circuit diagram of one variation of the lamp assembly shown in FIG. **2***a;*

FIG. **2***c* is a schematic circuit diagram of a ninth embodiment of the variable-effect lighting system;

FIG. **3** is a schematic circuit diagram of a tenth embodiment of the variable-effect lighting system, wherein the lamp controller directly drives each bicoloured lamp;

FIG. **4** is a night light according to one implementation of the embodiment shown in FIG. **2**;

FIG. **5***a* is a jewelry piece according to one implementation of the embodiment shown in FIG. **3**; and

FIG. **5***b* is a key chain according to another implementation of the embodiment shown in FIG. **3**.

DETAILED DESCRIPTION

Turning to FIG. **1***a*, a variable-effect lighting system, denoted generally as **10**, is shown comprising a lamp assembly **11**, and a lamp controller **12** coupled to the lamp assembly **11** for setting the colour of light produced by the lamp assembly **11**. Preferably, the lamp assembly **11** comprises string of multi-coloured lamps **14** interconnected with flexible wire conductors to allow the ornamental lighting system **10** to be used as decorative Christmas tree lights. However, the multi-coloured lamps **14** may also be interconnected with substantially rigid wire conductors or affixed to a substantially rigid backing for applications requiring the lamp assembly **11** to have a measure of rigidity.

The multi-coloured lamps **14** are connected in series with each other and with an AC voltage source **16**, and a current-limiting resistor **18**. Typically the AC voltage source **16** comprises the 60 Hz 120 VAC source commonly available. However, other sources of AC voltage may be used without departing from the scope of the invention. As will be appreciated, the series arrangement of the lamps **14** eliminates the need for a step-down transformer between the AC voltage source **16** and the lamp assembly **11**. The current-limiting resistor **18** limits the magnitude of current flowing through the lamps **14**. However, the current-limiting resistor **18** may be eliminated if a sufficient number of lamps **14** are used, or if the magnitude of the voltage produced by the AC voltage source **16** is selected so that the lamps **14** will not be exposed to excessive current flow.

Preferably, each lamp **14** comprises a bicoloured LED having a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light which is different from the first colour, and with the leads of each lamp **14** disposed such that when current flows through the lamp **14** in one direction the first colour of light is produced, and when current flows through the lamp **14** in the opposite direction the second colour of light is produced. As shown in FIG. **1***a*, preferably each bicoloured LED comprises a pair of differently-coloured LEDs **14***a*, **14***b* connected back-to-back, with the first illuminating element comprising the LED **14***a* and the second illuminating element comprising the LED **14***b*.

In a preferred implementation, the first illuminating element produces red light, and the second illuminating element produces green light. However, other LED colours may be used if desired. In addition, both LEDs **14***a*, **14***b* of some of the lamps **14** may be of the same colour if it is desired that some of the lamps **14** vary the intensity of their respective colour outputs only. Further, each lamp **14** may be fitted with a translucent ornamental bulb shaped as a star, or a flower or may have any other aesthetically pleasing shape for added versatility.

Preferably, the lamp controller **12** comprises a microcontroller **20**, a bidirectional semiconductor switch **22** controlled by an output Z of the microcontroller **20**, and a user-operable switch **24** coupled to an input S of the microcontroller **20** for selecting the colour display desired. In addition, an input X of the microcontroller **20** is coupled to the AC voltage source **16** through a current-limiting resistor **26** for synchronization purposes, as will be described below. The bidirectional switch **22** is positioned in series with the lamps **14**, between the current limiting resistor **18** and ground. In FIG. **1***a*, the bidirectional switch **22** is shown comprising a triac switch. However, other bidirectional switches, such as IGBTs or back-to-back SCRs, may be used without departing from the scope of the invention.

The lamp controller **12** is powered by a 5-volt DC regulated power supply **28** connected to the AC voltage source **16** which ensures that the microcontroller **20** receives a steady voltage supply for proper operation. However, for added safety, the lamp controller **12** also includes a brownout detector **30** connected to an input Y of the microcontroller **20** for placing the microcontroller **20** in a stable operational mode should the supply voltage to the microcontroller **20** drop below acceptable limits.

Preferably, the microcontroller **20** includes a non-volatile memory which is programmed or "burned-in" with preferably several conduction angle patterns for setting the conduction angle of the bidirectional switch **22** in accordance with the pattern selected. In this manner, the conduction angles of the LEDs **14***a*, **14***b* (and hence the colour display generated by the bicoloured lamps **14**) can be selected. Alternately, the microcontroller **20** may be replaced with a dedicated integrated circuit (ASIC) that is "hard-wired" with one or more conduction angle patterns.

Preferred colour displays include, but are not limited to:

1. continuous slow colour change between red, amber and green

2. continuous rapid colour change between red, amber and green

3. continuous alternate flashing of red and green
4. continuous random flashing of red and green
5. continuous illumination of red only
6. continuous change in intensity of red
7. continuous flashing of red only
8. continuous illumination of green only
9. continuous change in intensity of green
10. continuous flashing of green only
11. continuous illumination of red and green to produce amber
12. combination of any of the preceding colour displays

However, as will be appreciated, the microcontroller **20** need only be programmed with a single conduction angle pattern to function. Further, the microcontroller **20** needs only to be programmed in situ with a user interface (not shown) for increased flexibility. As will be apparent, if the microcontroller **20** is programmed with only a single conduction angle pattern, the user-operable switch **24** may be eliminated from the lamp controller **12**. Further, the user-operable switch **24** may be eliminated even when the microcontroller **20** is programmed with a number of conduction angle patterns, with the microcontroller **20** automatically switching between the various conduction angle patterns. Alternately, the user-operable switch **24** may be replaced with a clock circuit which signals the microcontroller **20** to switch conduction angle patterns according to the time.

The operation of the variable-effect lighting system **10** will now be described. Prior to power-up of the lighting system **10**, the microcontroller **20** is programmed with at least one conduction angle pattern. Alternately, the microcontroller **20** is programmed after power-up using the above-described user interface. Once power is applied through the AC voltage source **16**, the 5-volt DC regulated power supply **28** provides power to the microcontroller **20** and the brown-out detector **30**.

After the brown-out detector **30** signals the microcontroller **20** at input Y that the voltage supplied by the power supply **28** has reached the threshold sufficient for proper operation of the microcontroller **20**, the microcontroller **20** begins executing instructions for implementing a default conduction angle pattern. However, if a change of state is detected at the input S by reason of the user activating the user-operable switch **24**, the microcontroller **20** will begin executing instructions for implementing the next conduction angle pattern. For instance, if the microcontroller **20** is executing instructions for implementing the third conduction angle pattern identified above, actuation of the user-operable switch **24** will force the microcontroller **20** to being executing instructions for implementing the fourth conduction angle pattern.

For ease of explanation, it is convenient to assume that the LED **14***a* is a red LED, and the LED **14***b* is a green LED. It is also convenient to assume that the first conduction angle pattern, identified above, is selected. The operation of the lighting system **10** for the remaining conduction angle patterns will be readily understood from the following description by those skilled in the art.

After the conduction angle pattern is selected, either by default or by reason of activation of the user-operable switch **24**, the microcontroller **20** will begin monitoring the AC signal received at the input X to the microcontroller **20**. Once a positive-going zero-crossing of the AC voltage source **16** is detected, the microcontroller **20** delays a predetermined period. After the predetermined period has elapsed, the microcontroller **20** issues a pulse to the bidirectional switch **22**, causing the bidirectional switch **22** to conduct current in the direction denoted by the arrow **32**. As a result, the red LED **14***a* illuminates until the next zero-crossing of the AC voltage source **16**. In addition, while the LED **14***a* is conducting current, the predetermined period for the LED **14***a* is increased in preparation for the next positive-going zero-crossing of the AC voltage source **16**.

After the negative-going zero-crossing of the AC signal source **16** is detected at the input X, the microcontroller **20** again delays a predetermined period. After the predetermined period has elapsed, the microcontroller **20** issues a pulse to the bidirectional switch **22**, causing the bidirectional switch **22** to conduct current in the direction denoted by the arrow **34**. As a result, the green LED **14***b* illuminates until the next zero-crossing of the AC voltage source **16**. In addition, while the LED **14***b* is conducting current, the predetermined period for the LED **14***b* is decreased in preparation for the next negative-going zero-crossing of the AC voltage source **16**.

With the above conduction angle sequence, it will be apparent that the period of time each cycle during which the red LED **14***a* illuminates will continually decrease, while the period of time each cycle during which the green LED **14***b* illuminates will continually increase. Therefore, the colour of light emanating from the bicoloured lamps **14** will gradually change from red, to amber, to green, with the colour of light emanating from the lamps **14** when both the LEDs **14***a*, **14***b* are conducting being determined by the instantaneous ratio of the magnitude of the conduction angle of the LED **14***a* to the magnitude of the conduction angle of the LED **14***b*.

When the conduction angle of the green LED **14***b* reaches 180°, the conduction angle pattern is reversed so that the colour of light emanating from the bicoloured lamps **14** changes from green, to amber and back to red. As will be appreciated, the maximum conduction angles for each conducting element of the lamps **14** can be set less than 180° if desired.

In a preferred implementation, the microcontroller **20** comprises a Microchip PIC12C508 microcontroller. The zero-crossings of the AC voltage source **16** are detected at pin **3**, the state of the user-operable switch **24** is detected at pin **7**, and the bidirectional switch **22** is controlled by pin **6**. The brown-out detector **30** is coupled to pin **4**.

A sample assembly code listing for generating conduction angle patterns **1**, **2** and **3** with the Microchip PIC12C508 microcontroller is shown in Table A.

TABLE A

```
; Constants
  AC_IN EQU 4; GP4 (pin 3) is AC input pin X
  TRIGGER_OUT EQU 1; GP1 (pin 6) is Triac Trigger pin Z
  BUTTON EQU 0; GP0 (pin 7) is input pin S and is active low
  delay_dim EQU 0×007
  dim_val EQU 0×008
  trigger_delay EQU 0×009
  DELAY1 EQU 0×00A
  DELAY2 EQU 0×00B
  DELAY3 EQU 0×00C
  RED_INTENSITY EQU 0×00D
  SUBTRACT_REG EQU 0×00E
  DELAY5 EQU 0×00F
  FLASH_COUNT EQU 0×010
  FLASH_COUNT_SHAD EQU 0×011
  FADE_DELAY EQU 0×012
  org 0; RESET vector location
  movwf OSCCAL; move data from W register to OSCCAL
  goto START
DELAY; subroutine to delay 83 usec * register W
  movwf dim_val;
LOOP1
  movlw .27
  movwf delay_dim
LOOP2; delay 83 usec
  decfsz delay_dim,1
```

TABLE A-continued

```
   goto LOOP2
   decfsz dim_val,1
   goto LOOP1
return
TRIGGER; subroutine to send trigger pulse to triac
   bsf GPIO,TRIGGER_OUT
      movlw b'00010001'
      TRIS GPIO; send trigger to triac
   movlw .30
   movwf trigger_delay
LOOP3
   decfsz trigger_delay,1
   goto LOOP3; delay 30 usec
      movlw b'00010011'
      TRIS GPIO; remove trigger from triac
return
DELAY_SEC
   movlw .4
   movwf DELAY3;        set DELAY3
SEC2
   movlw .250
   movwf DELAY2;        set DELAY2
QUART_SEC2
   movlw .250
   movwf DELAY1;        set DELAY1
MSEC2
   clrwdt;   clear Watchdog timer
   decfsz DELAY1,1;     wait DELAY1
   goto MSEC2
   decfsz DELAY2,1;     wait DELAY2 * DELAY1
   goto QUART_SEC2
   decfsz DELAY3,1:     wait DELAY3 * DELAY2 * DELAY1
   goto SEC2
return
FADE_SUB;               subroutine to vary conduction angle for triac
                        each half cycle
UP_LOOP;                increase delay before triac starts to conduct
                        each negative half cycle while decreasing delay
                        each positive half cycle
   btfss GPIO,AC_IN
   goto UP_LOOP;        wait for positive swing on AC input
WAIT_NEG1
   call WAIT_NEG_EDGE1; increase delay before turning triacon each
                        negative half cycle
NO_CHANGE
   movlw .90; register W = maximum delay value
              before triac turns on
   subwf RED_INTENSITY,0
   btfsc STATUS,Z
   goto WAIT_NEG2; if RED_INTENSITY is equal to maximum
                   delay value, start increasing delay value
   movf RED_INTENSITY,0
   btfss GPIO,BUTTON
return;                 return if Button depressed
   call DELAY;          delay RED_INTENSITY * 83 usec
   call TRIGGER;        send trigger pulse to triac
MAIN_LOOP2
   btfsc GPIO,AC_IN
   goto MAIN_LOOP2; wait for negative swing on AC input
WAIT_POS_EDGE1
   btfss GPIO,AC_IN
   goto WAIT_POS_EDGE1; wait for positive swing on AC input
   movlw .96
   movwf SUBTRACT_REG; SUBTRACT_REG = maximum
                       delay value + minimum delay value
                       before triac turns on
   movf RED_INTENSITY,0
   subwf SUBTRACT_REG,0
   call DELAY; delay (SUBTRACT_RED-RED_
               INTENSITY) * 83 usec
   call TRIGGER; send trigger pulse to triac
   goto UP_LOOP
DOWN_LOOP
   btfss GPIO,AC_IN
   goto DOWN_LOOP; wait for positive swing on AC input
WAIT_NEG2
   call WAIT_NEG_EDGE2;    decrease delay before triac turns on each
                           negative half cycle
NO_CHANGE2
   movlw .6
```


TABLE A-continued

```
   subwf RED_INTENSITY,0; register W = RED_INTENSITY –
                          minimum delay value
   btfsc STATUS,Z
   goto WAIT_NEG1; if RED_INTENSITY is equal to minimum delay
                   value, start increasing delay
   movf RED_INTENSITY,0
   btfss GPIO,BUTTON
return;                 return if Button depressed
   call DELAY;          delay RED_INTENSITY * 83 usec
   call TRIGGER;        send trigger pulse to triac
MAIN_LOOP3
   btfsc GPIO,AC_IN
   goto MAIN_LOOP3; wait for negative swing on AC input
WAIT_POS_EDGE2
   btfss GPIO,AC_IN
   goto WAIT_POS_EDGE2; wait for positive swing on AC input
   movlw .96
   movwf SUBTRACT_REG; SUBTRACT_ REG = maximum delay
                       value before triac turns on
   movf RED_INTENSITY,0
   subwf SUBTRACT_REG,0
   call DELAY; delay (SUBTRACT_REG-RED_INTENSITY) * 83 usec
   call TRIGGER; send trigger pulse to triac
   goto DOWN_LOOP
return
WAIT_NEG_EDGE1; routine to increase delay before triac turns
     ; on each negative half cycle
   btfsc GPIO,AC_IN; wait for negative swing on AC input
   goto WAIT_NEG_EDGE1
   decfsz DELAY5,1; DELAY5 = fade delay (number of cycles at
                    present delay) value; decrement and
                    return if not zero
return
   incf RED_INTENSITY,1; otherwise, increment delay and return
   movf FADE_DELAY,0
   movwf DELAY5
return
WAIT_NEG_EDGE2; routine to decrease delay before triac turns
                on each negative half cycle
   btfsc GPIO,AC_IN; wait for negative swing on AC input
   goto WAIT_NEG_EDGE2
   decfsz DELAY5,1; DELAY5 = number of cycles at present
                    delay value; decrement and return if not zero
return
   decf RED_INTENSITY,1; otherwise decrement delay and return
   movf FADE_DELAY,0
   movwf DELAY5; DELAY5 = FADE_DELAY
return
FLASH_SUB; subroutine to flash lights at speed dictated by
value assigned to FLASH_COUNT_SHAD
   movf FLASH_COUNT_SHAD,0
   movwf FLASH_COUNT; FLASH_COUNT = duration of flash
MAIN_LOOP4
   btfsc CPIO,AC_IN; wait for negative swing on AC input
   goto MAIN_LOOP4
WAIT_POS_EDGE4
   btfsc GPIO,AC_IN
   goto WAIT_POS_EDGE4; wait for positive swing on AC input
   movlw .6
   call DELAY
   call TRIGGER; send trigger pulse to triac
   btfss GPIO,BUTTON
return; return if Button pressed
   decfsz FLASH_COUNT
   goto MAIN_LOOP4; decrement FLASH_COUNT and
   repeat until zero
   movf FLASH_COUNT_SHAD,0
   movwf FLASH_COUNT; reset FLASH_COUNT
DOWN_LOOP4
   btfss GPIO,AC_IN; wait for positive swing on AC input
   goto DOWN_LOOP4
WAIT_NEG_EDGE4
   btfsc GPIO,AC_IN
   goto WAIT_NEG_EDGE4; wait for negative swing on AC input
   movlw .6
   call DELAY
   call TRIGGER send trigger pulse to triac
   btfss GPIO,BUTTON
return; return if Button pressed
   decfsz FLASH_COUNT
```

TABLE A-continued

```
    goto DOWN_LOOP4; decrement FLASH_COUNT and
    repeat until zero
return
START
    movlw b'00010011'
    TRIS GPIO; set pins GP4 (AC input), GP1 (Triac output to high
    impedance), GPO (Button as input)
    movlw b'10010111'; enable pullups on GPO, GP1, GP3
OPTION
    movlw .4
    movwf RED_INTENSITY; load RED_INTENSITY register
    movlw .5
    movwf DELAY5; set initial fade
FADE_SLOW
    call DELAY_SEC; wait DELAY3 * DELAY2 * DELAY1
    movlw .5
    movwf FADE_DELAY; set slow FADE_DELAY
    call FADE_SUB; slowly fade colours until Button is pressed
    goto FADE_FAST
FADE_FAST
    call DELAY_SEC; wait DELAY3 * DELAY2 * DELAY1
    movlw .1
    movwf FADE_DELAY; set fast FADE_DELAY
    call FADE_SUB; rapidly fade colours until Button is pressed
    goto FLASH2_SEC
FLASH2_SEC ; flash red/green 2 sec interval
    call DELAY_SEC; wait DELAY3 * DELAY2 * DELAY1
    movlw .120
    movwf FLASH_COUNT_SHAD
FLASH2B_SEC
    btfss GPIO,BUTTON
    goto FLASH1_SEC; slowly flash lights until Button is pressed
    call FLASH_SUB
    goto FLASH2B_SEC
FLASH1_SEC ; flash red/green 1 sec. interval
    call DELAY_SEC; wait DELAY3 * DELAY2 * DELAY1
    movlw .60
    movwf FLASH_COUNT_SHAD
FLASH1B_SEC
    btfss GPIO,BUTTON
    goto FLASH_FAST; flash lights at moderate speed until
Button is pressed
    call FLASH_SUB
    goto FLASH1B_SEC
FLASH_FAST ; flash red/green 0.25 sec. interval
    call DELAY_SEC; wait DELAY3 * DELAY2 * DELAY1
    movlw .15
    movwf FLASH_COUNT_SHAD
FLASH_FASTB
    btfss GPIO,BUTTON
    goto FADE_SLOW; rapidly flash lights until Button is pressed
    call FLASH_SUB; slowly fade colours if Button is pressed
    goto FLASH_FASTB
end
```

Numerous variations of the lighting system **10** are possible. In one variation (not shown), the user-operable switch **24** is replaced with a temperature sensor coupled to the input S of the microcontroller **20** for varying the conduction angle pattern according to the ambient temperature. Alternately, the lamp controller **12** includes a plurality of temperature sensors, each being sensitive to a different temperature range, and being coupled to a respective input of the microcontroller **20**. With this variation, one colour display is produced when the ambient temperature falls within one range and another colour display is produced when the ambient temperature falls within a different range.

In another variation, the lamp controller **12** includes a motion or proximity sensor coupled to an appropriate input of the microcontroller **20**. With this variation, one colour display is produced when motion or an object (such as a person) is detected, and another colour display is produced when no motion or object is detected.

In yet another variation (not shown), each lamp **14** comprises a pair of LEDs with one of the LEDs being capable of

emitting white light and with the other of the LEDs being capable of producing a colour of light other than white. In still another variation, each lamp **14** comprises a LED capable of producing three or more different colours of light, while in the variation shown in FIG. **1***b*, each lamp **14** comprises three or more differently-coloured LEDs. In these latter two variations, the LEDs are connected such that when current flows in one direction one colour of light is produced, and when current flows in the opposite direction another colour of light is produced.

A second embodiment of the lighting system is depicted in FIG. **1***c*. As shown, the lamp controller **12** comprises two bidirectional switches **22***a*, **22***b* each connected to a respective output Z**1**, Z**2** of the microcontroller **20**. The lamp assembly **11** comprises first and second strings **11***a*, **11***b* of series-connected back-to-back-coupled LEDs **14***a*, **14***b*, with each string **11***a*, **11***b* being connected to the AC voltage source **16** and to a respective one of the bidirectional switches **22***a*, **22***b*. In this variation, each multi-coloured lamp **14** comprises one pair of the back-to-back-coupled LEDs **14***a*, **14***b* of the first string **11***a* and one pair of the back-to-back-coupled LEDs **14***a*, **14***b* of the second string **11***b*, with the LEDs of each lamp **14** being inserted in a respective translucent ornamental bulb. As a result, the colour of light emanating from each bulb depends on the instantaneous ratio of the conduction angles of the LEDs **14***a*, **14***b* in both strings **11***a*, **11***b*. Preferably, the outputs Z**1**, Z**2** are independently operable to increase the range of colour displays.

In one variation, the lamp controller **12** is similar to the lamp controller **12** shown in FIG. **1***c*, in that it comprises two bidirectional switches **22***a*, **22***b* each connected to a respective independently-operable output Z**1**, Z**2** of the microcontroller **20**. However, unlike the lamp controller **12** shown in FIG. **1***c*, the lamp assembly **11** comprises first and second strings **11***a*, **11***b* of series-connected single-coloured lamps **14**. As above, each singly-coloured lamp **14** of the first string **11***a* is associated with a singly-coloured lamp **14** of the second string **11***b*, with each associated lamp pair being inserted in a respective translucent ornamental bulb.

A third embodiment of the lighting system is depicted in FIG. **1***d*. As shown, the lighting system **10'''** comprises a RC power-up circuit **30'** for placing the microcontroller **20** in a known state at power up, and an EEPROM **21** connected to the microcontroller **20** for retaining a data element identifying the selected conduction angle pattern so that the lighting system **110'''** implements the previously selected conduction angle pattern after power up. As will be apparent, the EEPROM **21** may be implemented instead as part of the microcontroller **20**.

The bidirectional semiconductor switch **22'''** of the lamp controller **12'''** of the lighting system **10'''** comprises a thyristor **22***c*, and a diode H-bridge **22***d*. The thyristor **22***c* is connected at its gate input to the output Z of the microcontroller **20**. The diode H-bridge **22***d* is connected between the anode of the thyristor **22***c* and the lamp assembly **11**. The diode H-bridge **22***d* comprises two legs of two series-connected diodes, and a 1 Meg-ohm resistor connected between one of the diode legs and signal ground for providing the microcontroller **20** with a fixed voltage reference for proper operation of the diode bridge **22***d*. The bidirectional switch **22'''** functions in a manner similar to the semiconductor switch **22**, but is advantageous since the cost of a thyristor is generally less than that of a triac.

A fourth embodiment of the lighting system is depicted in FIG. **1***e*. As shown, the bidirectional semiconductor switch $\mathbf{22}^{iv}$ of the lamp controller $\mathbf{12}^{iv}$ of the lighting system $\mathbf{10}^{iv}$ comprises the thyristor **22***c*, the diode H-bridge **22***d* and a

diode steering section **22***e*. The thyristor **22***c* is connected at its gate input to the output Z of the microcontroller **20**. The diode H-bridge **22***d* is connected to the anode of the thyristor **22***c*, and the diode steering section **22***e* is connected between the diode H-bridge **22***d* and the lamp assembly **11**.

The diode steering section **22***e* comprises a first steering diode in series with a first current-limiting resistor, and a second steering diode in series with a second current-limiting resistor. As shown, the first steering diode is connected at its anode to the diode H-bridge **22***d*, and is connected at its cathode to the first current-limiting resistor. The second steering diode is connected at its cathode to the diode H-bridge **22***d*, and is connected at its anode to the second current-limiting resistor.

In operation, when current flows from the voltage source through the lamps **14** in a first direction, the current is steered by the first steering diode through the first current-limiting resistor. When current flows from the voltage source through the lamps **14** in a second (opposite direction), the current is steered by the second steering diode through the second current-limiting resistor.

Typically, the forward voltage of the LEDs **14***a* may not be identical to the forward voltage of the LEDs **14***b*. As a result, generally the current conducted by the LEDs **14***a* may not be identical to the current conducted by the LEDs **14***b*. Therefore, the intensity of light produced by the LEDs **14***a* might not be identical to the intensity of light produced by the LEDs **14***b*. Further, even if the forward voltage of the LEDs **14***a* is the same as the forward voltage of the LEDs **14***b*, the intensity of light produced by the LEDs **14***a* might still not be identical to the intensity of light produced by the LEDs **14***b*. Using the diode steering section **22***e*, the intensity of light produced by the LEDs **14***a* can be matched to the intensity of light produced by the LEDs **14***b* by the appropriate selection of the values for the first and second current limiting resistors.

Although the diode steering section **22***e* is depicted in FIG. **1***e* as a separate circuit from the diode H-bridge **22***d*, the functionality of the diode steering section **22***e* can be incorporated into the diode H-bridge **22***d*, by relocating the first and second current-limiting resistors of the diode steering section **22***e* into respective legs of the diode H-bridge **22***d*, and eliminating the first and steering diodes. In this variant, the diodes of the H-bridge **22***d* would, in effect, perform the same function as the first and second steering diodes.

Further, the first and second current-limiting resistors of the diode steering section **22***e* are depicted in FIG. **1***e* as fixed resistances. However, the thyristor **22***c* and the diode H-bridge **22***d* can be eliminated, and the first and second current-limiting resistors replaced with electrically-variable resistors controlled by the microcontroller **20**. In this latter variant, the intensity/colour produced by each lamp **14** can be controlled without having to calculate the conduction interval for each illuminating element **14***a*, **14***b*.

Thus far in the discussion, it has been assumed that the frequency of the AC voltage source has been constant. In the algorithm implemented in the assembly code listing shown in Table A, it was assumed that the frequency of the AC voltage source was constant at 60 Hz. In practice, the frequency of the AC voltage source might not be constant. Alternately, the frequency of the AC voltage source might be constant at some value other than 60 Hz. For instance, in some countries, the AC voltage is delivered to households at approximately 50 Hz. In either of these cases, the lamp controller **12** configured with the algorithm implemented in the assembly code listing shown in Table A would produce unpredictable results since the remaining conduction intervals calculated by the algorithm for each half cycle of the voltage source will not reflect the actual remaining conduction intervals.

Specifically, if the frequency of the voltage source is lower than expected, the period of the voltage source will be longer than expected. A point will be reached where the algorithm assumes that the LEDs **14***a* are fully on, and the LEDs **14***b* are fully off, at which point the algorithm will begin to reverse (i.e. will decrease the conduction interval of the LEDs **14***a*, and will increase the conduction interval of the LEDs **14***b*). However, at this point, the LEDs **14***a* will not be fully on, and the LEDs **14***b* will note be fully off. As a result, the colour produced by each lamp **14** will not be as expected.

Conversely, if the frequency of the voltage source is higher than expected, the period of the voltage source will be shorter than expected. A point will be reached where the LEDs **14***a* are fully on, and the LEDs **14***b* are fully off. However, at this point, the algorithm will assume that the LEDs **14***a* are not quite fully on, and the LEDs **14***b* are not quite fully off, at which point the algorithm will continue to increase the conduction interval of the LEDs **14***a*, and will continue to decrease the conduction interval of the LEDs **14***b*. As a result, the LEDs **14***a*, **14***b* will be turned on during the wrong half of the voltage cycle, thereby producing an unpredictable visual display.

Accordingly, rather than the algorithm assuming a fixed source voltage frequency, preferably the algorithm implemented by the lamp controller **12** (in any of the preceding embodiments of the lighting system) measures the period of time between instances of zero voltage crossings of the AC source voltage, and uses the calculated period to calculate the line frequency of the AC source voltage. By using the calculated line frequency, the algorithm is able to accurately track the actual conduction interval for the LEDs **14** during each half cycle of the AC voltage. The algorithm can calculate the line frequency on a cycle-by-cycle basis. However, for greater accuracy, preferably the algorithm calculates the line frequency over several AC voltage cycles.

Thus far in this description, the user-operable switch **24** has been used to cycle between the different conduction angle patterns. According to a fifth embodiment, the lamp controller is configured with only a single conduction angle algorithm, such as a continuous colour change or a continuous intensity change, and the user-operable switch **24** is used to start/stop the variation in the conduction angle. As a result, the user is able to fix or set the colour or intensity produced by the lamp assembly as desired, by simply depressing the user-operable switch **24** when the lamp controller has produced the desired colour or intensity. As above, preferably the current conduction angle is stored in EEPROM when the user-operable switch **24** is activated so that the lamp controller **12** reimplements the selected colour or intensity, using the stored conduction angle, after power has been removed and then reapplied to the lighting system.

If the user wishes to select a different colour or intensity, the user depresses the user-operable switch **24** again, thereby causing the conduction angle algorithm to resume the variation in colour or intensity. The user then presses the user-operable switch **24** again when the lamp controller has produced the new desired colour or intensity.

A sample assembly code listing for fixing the desired colour using a Microchip PIC 12F629 microcontroller as the microcontroller **20** is shown below in Table B.

TABLE B

```
; The program consists of a fade routine in which the conduction angles of
; two sets of series-connected LEDs (connected back-to-back) are changed.
; During the SCR trigger pulse, the user-operable switch 24 is monitored.
; Activation of the switch 24 toggles a FLAG. If the switch 24 is pressed
; when the fade is occurring, the current conduction angles are kept
; steady. These values are also stored in EEPROM so that the information
; is retained in the event of a power loss. On power up, the previous
; state is retrieved from the EEPROM.
   LIST P = 12f629, F = INHX8M
         LIST FREE
      #include "p12f629.inc"
  ; Constants
Start_Stop EQU 0
Button EQU 0 ; Button on GPIO,0
AC_IN EQU 5 ; AC input on GPIO,5
TRIGGER_OUT EQU 1; Triac Trigger on GPIO,1
min intensity EQU .80 ; values for min and max delays of trigger pulse
max intensity EQU .30
Flag Address EQU 0 ; location where start/stop status is stored
Intensity Address EQU 1 ; location where current intensity is stored
Position_Address EQU 2 ; location which says where in the fade
routine program was ;
stopped
; variables
delay_dim EQU 0×020
dim val EQU O×021
trigger_delay EQU 0×022
RED_INTENSITY EQU 0×023
SUBTRACT_REG EQU 0×024
DELAY5 EQU 0×025
FADE_DELAY EQU 0×026
FLAG EQU 0×027
Dlay EQU 0×028
DELAY1 equ 0×029
DELAY2 equ 0×02a
DELAY3 equ 0×02b
ADDRESS equ 0×02C
DATA_B equ 0×02D
POSITION EQU 0×02E
   ORG 0×000 ; processor reset vector
   goto start ; go to beginning of program
org 0×007
WAIT_NEG_EDGE1 ; wait here till negative going pulse
   btfsc GPIO,AC_IN
   goto WAIT_NEG_EDGE1
   decfsz DELAY5,1; after FADE_DELAY counted down, increase
   RED_INTENSITY
   return
   btfss FLAG,Start_Stop ; if flag set, don't fade
      ; (i.e. don't increment intensity register)
   incf RED_INTENSITY,1
   movf FADE_DELAY,0
   movwf DELAY5
   return
WAIT_NEG_EDGE2
   btfsc GPIO,AC_IN
   goto WAIT_NEG_EDGE2
   decfsz DELAY5,1; after FADE_DELAY counted down, decrease
   RED_INTENSITY
   return
   btfss FLAG,Start_Stop ; if flag set, don't decrement intensity register
   decf RED_INTENSITY,1
   movf FADE_DELAY,0
   movwf DELAY5
   return
start
   call 0×3FF ; retrieve factory calibration value
   bsf STATUS,RP0 ; set file register bank to 1
   movwf OSCCAL ; update register with factory cal value
   movlw b'00000001' ; enable pullup on GPIO,0
   movwf WPU
   bcf STATUS,RP0 ; set file register bank to 0
   bcf FLAG,Start_Stop ; reset fade stop flag
   movlw b00000111'
   movwf CMCON
   movlw b00101011 ; GPO button input, GP1 trigger SCR
                          ; GP3 Reset, GPO A.C. timing pulse
   TRIS GPIO
   movlw b00011111' ; prescale wdt 128,
```


TABLE B-continued

```
   OPTION
   movlw max intensity
   movwf RED_INTENSITY
   movlw .7 ;
   movwf DELAY5 ; counter for FADE_DELAY determines fade speed
   movwf FADE_DELAY
   movlw Flag_Address ; check state (1 = fade stopped, 0 = fade)
   movwf ADDRESS
   call EE_READ
   movf DATA_B,0
   movwf FLAG ; only one bit used so can use reg.
   btfss FLAG,Start_Stop ;if fade stopped get intensity
   goto FADE_SLOWB ; otherwise continue
   movlw Intensity_Address
   movwf ADDRESS ; get intensity value
   call EE_READ
   movf DATA_B,0
   movwf RED_INTENSITY
   movlw Position Address ; find out where in program it was stopped
   movwf ADDRESS
   call EE_READ
   movf DATA_B,0
   movwf POSITION ; save position in POSITION variable
   movlw .1 ; determine where in program too jump to
   subwf POSITION,0
   btfsc STATUS,Z
   call POSITION1
   movlw .2
   subwf POSITION,0
   btfsc STATUS,Z
   call POSITION2
   movlw .3
   subwf POSITION,0
   btfsc STATUS,Z
   call POSITION3
   movlw .4
   subwf POSITION,0
   btfsc STATUS,Z
   call POSITION4
FADE_SLOWB ; fade between colors
   movlw .7 ; determines fade speed ie. 1 would be a fast fade
   movwf FADE_DELAY
   call WAIT_NEG1 ;
   movlw max_intensity
   movwf RED_INTENSITY
   goto FADE_SLOWB
DELAY
   movwf dim_val ; used to set up time to trigger scr
LOOP1
   movlw .27
   movwf delay_dim
LOOP2 decfsz delay_dim,1
   goto LOOP2
   decfsz dim_val,1
   goto LOOP1
   return
EE_READ ; routines to read and write to EEPROM
   movf ADDRESS,0
   bsf STATUS,RP0
   movwf EEADR
   bsf EECON1,RD
   movf EEDATA,w
   bcf STATUS,RP0
   movwf DATA_B
   return
EE_WRITE
   movf DATA_B,0
   bsf STATUS,RP0
   movwf EEDATA
   bcf STATUS,RP0
   movf ADDRESS,0
   bsf STATUS,RP0
   movwf EEADR
   bsf EECON1,WREN
   movlw 55h
   movwf EECON2
   movlw 0×0AA
   movwf EECON2
   bsf EECON1,WR
```

TABLE B-continued

```
Write_Loop
   btfsc EECON1,WR
   goto Write_Loop ; stay in loop till complete
   bcf EECON1,WREN
   bcf STATUS,RP0
   return
Check_Button
   movlw .4 ; check button and debounce
   movwf DELAY3
SEC2
   movlw .25
   movwf DELAY2
QUART_SEC2
   movlw .250
   movwf DELAY1
MSEC2
   clrwdt
   decfsz DELAY1,1
   goto MSEC2
   decfsz DELAY2,1
   goto QUART_SEC2
   decfsz DELAY3,1
   goto SEC2
   btfss GPIO,Button
   goto $-1
   movlw .4
   movwf DELAY3
SEC3
   movlw .250
   movwf DELAY2
QUART_SEC3
   movlw .25
   movwf DELAY1
MSEC3
   clrwdt
   decfsz DELAY1,1
   goto MSEC3
   decfsz DELAY2,1
   goto QUART_SEC3
   decfsz DELAY3,1
   goto SEC3
   movlw b'00000001' ;when button pressed toggle flag from stopped
         ; to fade position
   xorwf FLAG,1
   movlw Flag_Address
   movwf ADDRESS
   movf FLAG,0
   movwf DATA_B
   call EE_WRITE ; save values in EEPROM
   movlw Intensity_Address
   movwf ADDRESS
   movf RED_INTENSITY,0
   movwf DATA_B
   call EE_WRITE
   movlw Position_Address
   movwf ADDRESS
   movf POSITION,0
   movwf DATA_B
   call EE_WRITE
   return
TRIGGER      ; trigger pulse to SCR
             ; button press is checked during each trigger pulse
   clrwdt
   bsf GPIO,TRIGGER_OUT
   movlw b'00101001' ;
   TRIS GPIO
   movlw .30
   movwf trigger_delay
LOOP3
   decfsz trigger_delay,1
   goto LOOP3
   bcf GPIO,TRIGGER_OUT
   movlw b'00101011' ;
   TRIS GPIO
   btfss GPIO,Button ; if button pressed check it
   call Check_Button
   return
FADE_SUB ; subroutine for fading (4 positions in fade sequence)
```


TABLE B-continued

```
UP_LOOP
POSITION1
   movlw .1
   movwf POSITION
   btfss GPIO,AC_IN ;
   goto UP_LOOP ; RED LOOP
WAIT_NEG1
   call WAIT_NEG_EDGE1
NO_CHANGE
   movlw min_intensity ;
   subwf RED_INTENSITY,0
   btfsc STATUS,Z
   goto WAIT_NEG2 ;DOWN_LOOP
   movf RED_INTENSITY,0 ; (RED_INTENSITY-min_intensity)
   call DELAY
   call TRIGGER
MAIN_LOOP2
   btfsc GPIO,AC_IN
   goto MAIN LOOP2
WAIT_POS_EDGE1
   btfss GPIO,AC_IN
   goto WAIT_POS_EDGE1
   movlw max_intensity
   call DELAY
   call TRIGGER
   goto UP_LOOP
DOWN_LOOP
POSITION2
   movlw .2
   movwf POSITION
   btfss GPIO,AC_IN
   goto DOWN_LOOP
WAIT_NEG2
   call WAIT_NEG_EDGE2
NO_CHANGE2
   movlw max_intensity
   subwf RED_INTENSITY,0
   btfsc STATUS,Z
   goto GREEN_DOWN_RED_ON
   movf RED_INTENSITY,0
   call DELAY
   call TRIGGER
MAIN_LOOP3
   btfsc GPIO,AC_IN ;
   goto MAIN_LOOP3
WAIT_POS_EDGE2
   btfss GPIO,AC_IN
   goto WAIT_POS_EDGE2
   movlw max_intensity
   call DELAY
   call TRIGGER
   goto DOWN_LOOP
GREEN_DOWN_RED_ON
   movlw min_intensity
   movwf RED_INTENSITY
   goto WAIT_NEG2C
GREEN_DOWN_RED_ONB
POSITION3
   movlw .3
   movwf POSITION
   btfss GPIO,AC_IN ;
   goto GREEN_DOWN_RED_ONB
WAIT_NEG2C
   call WAIT_NEG_EDGE2
NO_CHANGE2C
   movlw max_intensity
   subwf RED_INTENSITY,0
   btfsc STATUS,Z
   goto WAIT_NEG1C
   movlw max_intensity
   call DELAY
   call TRIGGER
MAIN_LOOP3C
   btfsc GPIO,AC_IN
   goto MAIN_LOOP3C
WAIT_POS_EDGE2C
   btfss GPIO,AC_IN
   goto WAIT_POS_EDGE2C
   movlw min_intensity+max_intensity
   movwf SUBTRACT_REG
```

TABLE B-continued

```
    movf RED_INTENSITY,0
    subwf SUBTRACT_REG,0
    call DELAY
    call TRIGGER
    goto GREEN_DOWN_RED_ONB
GREEN_UP_RED_ON
POSITION4
    movlw .4
    movwf POSITION
    btfss GPIO,AC_IN ;
    goto GREEN_UP_RED_ON
WAIT_NEG1C
    call WAIT_NEG_EDGE1
NO_CHANGEC
    movlw min_intensity
    subwf RED_INTENSITY,0
    btfss STATUS,Z
    goto Continue_Loop
    movlw max_intensity ;start over
    movwf RED_INTENSITY
    goto WAIT_NEG1
Continue_Loop
    movlw max_intensity
    call DELAY
    call TRIGGER
MAIN_LOOP2C
    btfsc GPIO,AC_IN ;
    goto MAIN_LOOP2C
WAIT_POS_EDGE1C
btfss GPIO,AC_IN
    goto WAIT_POS_EDGE1C
    movlw max_intensity+min_intensity
    movwf SUBTRACT_REG
    movf RED_INTENSITY,0
    subwf SUBTRACT_REG,0
    call DELAY
    call TRIGGER
    goto GREEN_UP_RED_ON
        ;
    end
```

In a sixth embodiment (not shown), the lamp controller includes two user-operable inputs, and implements both the colour/intensity selection algorithm of the fifth embodiment and the multiple conduction angle pattern algorithms of the first through fourth embodiments. In this sixth embodiment, one of the user-operable inputs is used to select the desired conduction angle pattern, and the other user-operable inputs is used to start/stop the selected conduction angle pattern at a desired point.

An inherent advantage of each of the preceding embodiments is that they are all self-synchronizing. For instance, in each the preceding embodiments, if multiple lamp controllers were powered by a common AC voltage source, and were configured with the same predetermined display pattern(s), the visual display produced by each corresponding lamp assembly would be synchronized with the visual display produced by the other lamp assemblies. Thus, for example, in a household environment where several 120 VAC receptacles are connected in parallel with the same voltage source, all lamp assemblies would be synchronized with one another, even if the corresponding lamp controllers were plugged into different receptacles.

In each of the foregoing sample algorithms, the value of the RED_INTENSITY variable is increased/decreased after FADE_DELAY iterations of the WAIT_NEG_EDGE**1** and WAIT_NEG_EDGE**2** subroutines. Since the value of the RED_INTENSITY variable determines the conduction interval of each of the LEDs **14**, the rate of change of the colour produced by the lamp assembly is fixed by the value assigned to the FADE_DELAY variable. In a seventh embodiment, the rate of change of colour is not fixed but is determined by a signal source external to the lamp controller. In this embodiment, instead of the WAIT_NEG_EDGE**1** and WAIT_NEG_EDGE**2** subroutines increasing/decreasing the value of the RED_INTENSITY variable at a predetermined rate, the algorithm increases/decreases the value assigned to the RED_INTENSITY variable based on an external signal. Preferably, the value assigned to the RED_INTENSITY variable is based on a digital signal applied to the lamp controller, such as a DMX signal. However, in one variation, the microcontroller includes an analog-to-digital converter, and the value assigned to the RED_INTENSITY variable is based on the magnitude of an analog signal applied to the input of the analog-to-digital converter. An advantage of this embodiment is that the user is not confined to a predetermined set of visual effects, but can control the visual effect produced by the lamp assembly based on an external electrical signal applied to the lamp controller.

Turning to FIG. **2***a*, a variable-effect lighting system according to an eighth embodiment, denoted generally as **110**, is shown comprising a lamp assembly **111**, and a lamp controller **112** coupled to the lamp assembly **111** for setting the colour of light produced by the lamp assembly **111**.

The lamp assembly **111** comprises a string of multi-coloured lamps **114** connected in parallel with each other. The multi-coloured lamps **114** are also connected in parallel with an AC/DC converter **116** which is coupled to an AC voltage source. Each lamp **114** comprises a bicoloured LED having a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light which is different from the first colour, with the leads of each lamp **114** configured such that when current flows through one lead the first colour of light is produced, and when current flows through the another lead the second colour of light is produced. As shown in FIG. **2***a*, preferably each bicoloured LED comprises first and second differently-coloured LEDs **114***a*, **114***b* in series with a respective current-limiting resistor **118**, with the common cathode of the LEDs **114** being connected to ground, and with the first illuminating element comprising the first LED **114***a* and the second illuminating element comprising the second LED **114***b*.

The AC/DC converter **116** produces a DC output voltage of a magnitude which is sufficient to power the lamps **114**, but which will not damage the lamps **114**. Typically, the AC/DC converter **116** receives 120 volts AC at its input and produces an output voltage of about 5 volts DC.

Preferably, the controller **112** is also powered by the output of the AC/DC converter **116** and comprises a microcontroller **20**, a first semiconductor switch **122** controlled by an output Z1 of the microcontroller **20**, a second semiconductor switch **123** controlled by an output Z2 of the microcontroller **20**, and a user-operable switch **24** coupled to an input S of the microcontroller **20** for selecting the colour display desired. As discussed above, the user-operable switch **24** may be eliminated if desired. In FIG. **2***a*, the semiconductor switches **122**, **123** are shown comprising MOSFET switches. However, other semiconductor switches may be used without departing from the scope of the invention.

The first semiconductor switch **122** is connected between the output of the AC/DC converter **116** and the anode of the first LED **114***a* (through the first current-limiting resistor **118**), while the second semiconductor switch **123** is connected between the output of the AC/DC converter **116** and the anode of the second LED **114***b* (through the second current-limiting resistor **118**). However, the anodes of the LEDs **114***a*, **114***b* may be coupled instead to the output of the AC/DC converter, with the first and second semiconductor switches **122**, **123** being connected between the respective

cathodes and ground. Other variations on the placement of the semiconductor switches **122**, **123** will be apparent to those skilled in the art.

As with the previously described embodiments, the microcontroller **20** includes a non-volatile memory which is programmed with preferably several conduction angle sequences for setting the firing angle of the semiconductor switches **122**, **123** in accordance with the sequence selected. In this manner, the conduction angles of the LEDs **114***a*, **114***b*, and hence the ultimate colour display generated by the lamps **114** can be selected. Alternately, as discussed above, the microcontroller **20** may be replaced with a dedicated integrated circuit (ASIC) that is "hard-wired" with one or more conduction angle sequences.

The operation of the variable-effect lighting system **110** is similar to the operation of the variable-effect lighting system **10**. After power is applied to the AC/DC converter **116**, the microcontroller **20** begins executing instructions for implementing one of the conduction angle sequences. Again, assuming that the first conduction angle sequence, identified above, is selected, the microcontroller **20** issues a signal to the first semiconductor switch **122**, causing the first LED **114***a* to illuminate. After a predetermined period has elapsed, the signal to the first semiconductor switch **122** is removed, causing the first LED **114***a* to extinguish. While the LED **114***a* is conducting current, the predetermined period for the first LED **114***a* is decreased in preparation for the next cycle.

The microcontroller **20** then issues a signal to the second semiconductor switch **123**, causing the second LED **114***b* to illuminate. After a predetermined period has elapsed, the signal to the second semiconductor switch **123** is removed, causing the second LED **114***b* to extinguish. While the second LED **114***b* is conducting current, the predetermined period for the second LED **114***b* is increased in preparation for the next cycle.

With the above conduction angle sequence, it will be apparent that the period of time each cycle during which the first LED **114***a* illuminates will continually decrease, while the period of time each cycle during which the second LED **114***b* illuminates will continually increase. Therefore, the colour of light emanating from the lamps **114** will gradually change from the colour of the first LED **114***a* to the colour of the second LED **114***b*, with the colour of light emanating from the lamps **114** when both the LEDs **114***a*, **114***b* are conducting being determined by the instantaneous ratio of the magnitude of the conduction period of the first LED **114***a* to the magnitude of the conduction period of the second LED **114***b*.

Numerous variations of the lighting system **110** are also possible. In one variation, each lamp **114** comprises a pair of LEDs with one of the LEDs being capable of emitting white light and with the other of the LEDs being capable of producing a colour of light other than white. In another variation, each lamp **114** comprises a LED capable of producing three or more different colours of light, while in the variation shown in FIG. **2***b*, each lamp **114** comprises three or more differently-coloured LEDs. In these latter two variations, the LEDs are connected such that when current flows through one of the semiconductor switches one colour of light is produced, and when current flows through the other of the semiconductor switches another colour of light is produced.

A ninth embodiment of the lighting system is depicted in FIG. **2***c*. As shown, the controller **112** includes a first pair of electronic switches **122***a*, **122***b* driven by the output Z**1** of the microcontroller **20**, and a second pair of electronic switches **123***a*, **123***b* driven by the output Z**1** of the microcontroller **20**. Each pair of first and second LEDs **114***a*, **114***b* of each lamp **114** are connected back-to-back, such that the lamps **114** and the semiconductor switches **122**, **123** are configured together as an H-bridge. As discussed above, preferably the first and second LEDs **114***a*, **114***b* produce different colours, although the invention is not intended to be so limited.

Turning to FIG. **3**, a variable-effect lighting system according to a tenth embodiment, denoted generally as **210**, is shown comprising a multi-coloured lamp **214**, and a lamp controller **212** coupled to the multi-coloured lamp **214** for setting the colour of light produced by the lamp **214**. The multi-coloured lamp **114** comprises a bicoloured LED having a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light which is different from the first colour. As shown in FIG. **3**, preferably the first illuminating element comprises a red-coloured LED **214***a*, and the second illuminating element comprises a green-coloured LED **214***b*, with the common cathode of the LEDs **214***a*, **214***b* being connected to ground. As discussed above, multi-coloured LEDs and/or arrangements of differently-coloured discrete LEDs and/or translucent ornamental bulbs may be used if desired.

The lamp controller **212** is powered by a 9-volt battery **216**, and comprises a microcontroller **20**, and a user-operable switch **24** coupled to an input S of the microcontroller **20** for selecting the colour display desired. Alternately, for applications where space is at a premium, the lamp controller **212** may be powered by a smaller battery producing a smaller voltage. If necessary, the smaller battery may be coupled to the lamp controller **212** through a voltage amplifier, such as a DC-to-DC converter.

As discussed above, the microcontroller **20** may be replaced with a dedicated integrated circuit (ASIC) that is "hard-wired" with one or more conduction angle sequences. Also, the user-operable switch **24** may also be eliminated if desired.

An output Z**1** of the microcontroller **20** is connected to the anode of the red LED **214***a*, and an output Z**2** of the microcontroller **20** is connected to the anode of the green LED **214***b*. Since the lamp **214** is driven directly by the microcontroller **20**, the variable-colour ornamental lighting system **210** is limited to applications requiring only a small number of lamps **214**.

The operation of the variable-effect lighting system **210** will be readily apparent from the foregoing discussion and, therefore, need not be described.

Turning now to FIG. **4**, a night light **310** is shown comprising the variable-effect lighting system **110**, described above, but including only a single multi-coloured lamp **114**, a housing **340** enclosing the lamp controller **112** and the AC/DC converter **116**, and a translucent bulb **342** covering the lamp **114** and fastened to the housing **340**. Preferably, the housing **340** also includes an ambient light sensor **344** connected to the microcontroller **20** for inhibiting conduction of the lamp **114** when the intensity of ambient light exceeds a threshold.

In FIG. **5***a*, a jewelry piece **410**, shaped as a ring, is shown comprising the variable-effect lighting system **210**, described above, and a housing **440** retaining the lamp **214**, the lamp controller **212**, and the battery **216** therein. A portion **442** of the housing **440** is translucent to allow light to be emitted from the lamp **214**. In FIG. **5***a*, a key chain **510**, is shown comprising the variable-colour ornamental lighting system **210**, and a housing **540** retaining the lamp **214**, the lamp controller **212**, and the battery **216** therein. A portion **542** of the housing **540** is translucent to allow light to be emitted from the lamp **214**. A key clasp **544** is coupled to the housing **540** to retain keys. Both the jewelry piece **410** and the key chain **510** may optionally include a user-operable input for selecting the conduction angle pattern.

The invention claimed is:

1. A variable-effect lighting system comprising:

a lamp assembly comprising a plurality of multi-coloured lamps in series with an AC voltage source and in series with each other, the voltage source having a frequency, each said multi-coloured lamp comprising a first illuminating element for producing a first colour of light, and a second illuminating element for producing a second colour of light; and

a lamp controller coupled to the lamp assembly for controlling a current draw of each said illuminating element, the controller being configured to adjust the current draw in accordance with the voltage frequency.

2. The lighting system according to claim **1**, wherein the lamp controller includes an electronic switch coupled to the multi-coloured lamps, the electronic switch including a diode steering section coupled to the multi-coloured lamps for equalizing an intensity of the first colour with an intensity of the second colour.

3. The lighting system according to claim **2**, wherein the diode steering section comprises a first steering diode in series with a first current-limiting resistor, and a second steering diode in series with a second current-limiting resistor, the first steering diode being disposed to conduct a current through the multi-coloured lamps in a first direction and to block said current in a second direction opposite the first direction, the second steering diode being disposed to conduct said current in the second direction and to block said current in the first direction.

4. The lighting system according to claim **3**, wherein the first and second current-limiting resistors comprise electronically-variable resistors, and the electronic switch comprises a resistor controller coupled to the electronically-variable resistors for controlling a magnitude of a current through each said illuminating element.

5. The lighting system according to claim **3**, wherein the first and second current-limiting resistors comprise fixed resistances, and the resistance of the first current-limiting resistor is different than the resistance of the second current-limiting resistor.

6. The lighting system according to claim **2**, wherein the electronic switch comprises a diode H-bridge, a thyristor coupled to the diode H-bridge, and a switch controller coupled to the thyristor for controlling a conduction interval of each said illuminating element, the diode H-bridge including the diode steering section.

7. The lighting system according to claim **2**, wherein the electronic switch comprises a diode H-bridge coupled to the diode steering section, a thyristor coupled to the diode H-bridge, and a switch controller coupled to the thyristor for controlling a conduction interval of each said illuminating element, the diode H-bridge being distinct from the diode steering section.

8. The lighting system according to claim **2**, wherein the electronic switch comprises an electronically-variable resistor coupled to the diode steering section, and a resistor controller coupled to the electronically-variable resistor for controlling a magnitude of a current through each said illuminating element.

9. The lighting system according to any claim **1**, wherein the voltage source has a first voltage phase and a second voltage phase opposite the first phase, the first illuminating elements are configured to produce the first colour of light during the first voltage phase, and the second illuminating elements are configured to produce the second colour of light during the second voltage phase, the second colour being different from the first colour.

10. The lighting system according to claim **9**, wherein each said multi-coloured lamp comprises a pair of light-emitting diodes connected back-to-back, a first light-emitting diode of the light-emitting diode pair comprising the first illuminating element and a second light-emitting diode of the light-emitting diode pair comprising the second illuminating element.

11. The lighting system according to claim **1**, wherein the lamp controller includes a proximity sensor, and the lamp controller is configured to select the conduction interval of each said illuminating element according to one of proximity and motion detected by the proximity sensor.

12. The lighting system according to any claim **1**, wherein the lamp controller is configured to adjust the conduction interval of each said illuminating element according to a user-operable input to the controller.

* * * * *